Examining and Supporting Multi-Tasking in EV3OSEK

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Outline

Introduction of EV3OSEK

Application Model

Issues in EV3OSEK

Proposed Solutions

Evaluation

Current State of EV3OSEK
EV3OSEK

- EV3OSEK is an OS for Lego Mindstorms EV3 (2013).
  - aims to fulfil the OSEK standard.
  - NXTOSEK port by Westsächsische Hochschule Zwickau.
EV3OSEK

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- SoC Texas Instruments AM1808
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- SoC Texas Instruments AM1808
  - ARM926EJ-S
  - ARM9
  - 300MHz
  - 64 MB RAM
Application Model

- Priority decreases with higher indices:
  \[ p(\tau_i - 1) > p(\tau_i) > p(\tau_{i+1}) \].
- Deadlines are implicit: \[ T_i = D_i \]
- Job misses deadline: related release is skipped.

\[ \tau_1(4, 8) \]
NXTOSEK and EV3OSEK

- NXTOSEK is an OS for Lego Mindstorms NXT (2006).
  - uses Toppers/JSP or Toppers/ATK(OSEK) kernel.
  - has to be flashed on the brick.

Figure: http://lejos-osek.sourceforge.net/
NXTOSEK and EV3OSEK

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  - uses Toppers/JSP or Toppers/ATK(OSEK) kernel.
  - has to be flashed on the brick.
- Only the Toppers ATK(OSEK) kernel has been ported to EV3.
- ECRobot API in EV3OSEK supports less hardware in EV3.

Figure: http://lejos-osek.sourceforge.net/
Issues in NXTOSEK

- NXTOSEK is not able to provide nested preemption.

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![Diagram showing preemption times for tasks τ₁(2, 9), τ₂(2, 8), and τ₃(2, 7) with time t ranging from 0 to 20.](image)
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Issue in EV3OSEK

- The same issue as described by Gupta and Doshi was observed in EV3OSEK.

![Diagram showing execution overrun of \( \tau_2 \) and \( \tau_3 \)]
The same issue as described by Gupta and Doshi was observed in EV3OSEK.

- Preempted jobs re-execute.

Execution overrun of $\tau_2$

Execution overrun of $\tau_3$
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- Re-execution leads to longer WCET.
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- Execution overrun of \( \tau_2 \)
- Execution overrun of \( \tau_3 \)

- Preempted jobs re-execute.
- Re-execution leads to longer WCET.
- Longer WCET leads to deadline misses.
Issues in EV3OSEK

- What is the cause of re-execution?
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  - Context switching has to be erroneous.
  - Handled by: IRQ-handler and the dispatch routines.
  - IRQ-Handler is a rewrite.
  - Dispatch routines are ported from NXTOSEK.
EV3OSEKs Interrupt Routines

1. Issue:
The status register is not part of context switching.

2. Issue:
The lookup register is overwritten.

3. Issue:
The dispatch routine is loaded with an offset of $-4$.

4. Diagram:
   - IRQHandler:
     - Save context.
     - Was ISR systick_ISR_c?
       - False:
         - Restore context.
       - True:
         - Handle Interrupt.
     - should_dispatch == 0?
       - False:
         - Store Context. Load Dispatch.
       - True:
1 Issue: Status register is not part of context switching.
EV3OSEKs Interrupt Routines

1. **Issue:** Status register is not part of context switching.
2. **Issue:** The lookup register is overwritten.
**EV3OSEKs Interrupt Routines**

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Fixing EV3OSEKs IRQ-Handler

- Status register has to be part of save context routines.

IRQHandler:
- STMFD r13!, {r0-r12, lr} @ push r0-r12 and lr
Fixing EV3OSEKs IRQ-Handler

• Status register has to be part of save context routines.

IRQHandler:
+ SUB lr, lr, #0x4 @ remove offset from lr
+ STMFD r13!, {r0-r12} @ push r0-r12
+ STMFD r13!, {lr} @ push lr
+ MRS r0, spsr @ load spsr to r0
+ STMFD r13!, {r0} @ push spsr
Fixing EV3OSEKs IRQ-Handler

• Status register has to be part of restore context routines.

SkipButtons:
- LDMFD r13!, {r0-r12, lr} @ restore r0-r12 and lr
- SUBS pc, lr, #0x4 @ jump to address lr-4
Fixing EV3OSEKs IRQ-Handler

- Status register has to be part of restore context routines.

SkipButtons:
+ LDMFD r13!, {r0} @ pop spsr
+ MSRNE spsr_cxsf, r0 @ restore spsr
+ LDMFD r13!, {lr} @ restore lr
+ LDMFD r13!, {r0-r12} @ restore r0-r12
+ MOVS pc, lr @ jump to address lr
Fixing EV3OSEKs IRQ-Handler

- The lookup register is overwritten and has to be pushed to system stack, before leaving interrupt-handler.
- The dispatch routine is loaded with an offset of $-4$.

- LDMFD r13!, {r0-r12, lr} @ pop r0-r12 and lr
- LDR lr, =dispatch @ load jump address to lr
- SUBS pc, lr, #4 @ jump to address in lr
Fixing EV3OSEKs IRQ-Handler

- The lookup register is overwritten and has to be pushed to system stack, before leaving interrupt-handler.
- The dispatch routine is loaded with an offset of $-4$.

```assembly
+ LDMFD r13!, {r0} @ pop spsr in r0
+ MSRNE spsr_cxsf, r0 @ restore spsr
+ LDMFD r13!, {r2} @ pop lr in r2
+ MSR cpsr_c, #MODE_SYS|I_F_BIT @ Change to System-mode
+ STMFD r13!, {r2} @ push lr on System-stack
+ MSR cpsr_c, #MODE_IRQ|I_F_BIT @ Return to IRQ-mode
+ LDMFD r13!, {r0-r12} @ pop r0-r12
+ LDR lr, =dispatch_irq @ jump to dispatch
+ MOVS pc, lr
```
Fixing EV3OSEKs IRQ-Handler

IRQHandler:

Save context.

Was ISR systick_ISR_c?

False

Restore context.

True

Handle Interrupt.

should_dispatch == 0?

False

Store Context. Load Dispatch.

True
Dispatch Routines

- **Dispatch**: Current task is saved and relinquishes CPU.
- **Preempt**: Higher priority task is loaded and finishes execution.
- **Reload**: Preempted task is restored to CPU.
- **Issue**: The status register is neither saved, nor restored.

Diagram:
- **dispatch**: Dispatch
- **High priority task**: Preempt
- **start_dispatch**: Reload
- **dispatch_task**:
EV3OSEKs Dispatch Routines

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Fixing EV3OSEKs Dispatching Routines

- The status register is neither saved, nor restored.

```
dispatcher_r:
   BL    IntMasterIRQEnable    @ enable interrubs
   BL    IntMasterFIQEnable
   ldmfd sp!, {r0-r12}         @ restore r0-r12
   ldmfd sp!, {lr}             @ restore spsr value in lr
   mov   pc, lr                @ jump to lr
```
Fixing EV3OSEKs Dispatching Routines

- The status register is neither saved, nor restored.

```assembly
dispatch:
+ stmfd sp!, {lr} @ push lr
+dispatch_irq: @ lr already pushed by IRQ-Handler
+ mrs lr, spsr @ save spsr in lr
+ stmfd sp!, {lr} @ push spsr
+ stmfd sp!, {r0-r12} @ push r0-r12

dispatcher_r:
    BL IntMasterIRQEnable @ enable interrupts
    BL IntMasterFIQEnable
    ldmfd sp!, {r0-r12} @ restore r0-r12
    ldmfd sp!, {lr} @ restore spsr value in lr
+ msrne spsr_cxsf, lr @ write lr in spsr
+ ldmfd sp!, {lr}^ @ restore lr and write spsr to cpsr
    mov pc, lr @ jump to lr
```
Fixing EV3OSEKs Dispatching Routines

- dispatch:
  - Dispatch
    - High priority task:
      - Preempt
        - start_dispatch:
          - dispatch_task:
            - dispatch_r:
              - Reload
Evaluation

• Old dispatching routine of EV3OSEK:

![Diagram showing execution overrun for τ2 and τ3]

• Corrected dispatching routine of EV3OSEK:
Evaluation

- Example to verify the functional correctness of the dispatcher.
Evaluation

• Example to verify the functional correctness of the dispatcher.

• The tasks are specified as:
  
  • \( \tau_1 = (2, 5) \)
  • \( \tau_2 = (2, 8) \)
  • \( \tau_3 = (2, 10) \)

\[
\begin{bmatrix}
    l_1 \\
    l_2 \\
    l_3
\end{bmatrix} = \begin{bmatrix}
    8 \\
    4 \\
    4 \times t
\end{bmatrix} = \begin{bmatrix}
    2t \\
    1.25t \\
    t
\end{bmatrix}
\]
Evaluation

- Example to verify the functional correctness of the dispatcher.
- The tasks are specified as:
  - $\tau_1 = (2, 5)$
  - $\tau_2 = (2, 8)$
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- These tasks have a hyper-period of 40 seconds.

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- Example to verify the functional correctness of the dispatcher.
- The tasks are specified as:
  - $\tau_1 = (2, 5)$
  - $\tau_2 = (2, 8)$
  - $\tau_3 = (2, 10)$
- These tasks have a hyper-period of 40 seconds.
- This equation determines how many jobs are on average released in the intervals of length $t = 10$ seconds.

\[
\begin{pmatrix}
  l_1 \\
  l_2 \\
  l_3
\end{pmatrix}
= \begin{pmatrix}
  \frac{8}{4} \\
  \frac{5}{4} \\
  \frac{4}{4}
\end{pmatrix}
\times t
= \begin{pmatrix}
  2t \\
  1.25t \\
  t
\end{pmatrix}
\]
Evaluation

• To verify that the stack and the lookup register are handled correctly, the example is executed for 600 seconds (10 min).

\[ t = 600\,001\,ms \approx 60 \times 10\,\text{sec} \Rightarrow \begin{cases} l_1(60) = 120 \\ l_2(60) = 75 \\ l_3(60) = 60 \end{cases} \]
Evaluation

\[ t = 600001 \text{ (ms)} \approx 60 \times 10 \text{sec} \Rightarrow \begin{pmatrix} l_1(60) = 120 \\ l_2(60) = 75 \\ l_3(60) = 60 \end{pmatrix} \]

Task \( i(l_1(t), l_2(t), l_3(t)) \) start at \( t \times 10^4 \).

Task 1(0, 0, 0) start at 1.
Task 1(1, 0, 0) end at 2005.
Task 2(1, 0, 0) start at 2008.
Task 2(1, 1, 0) end at 4003.
Task 3(1, 1, 0) start at 4005.
Task 1(1, 1, 1) start at 5001.
Task 1(2, 1, 1) end at 6995.
... 
Task 1(119, 75, 60) start at 595001.
Task 1(120, 75, 60) end at 596996.
Task 3(120, 75, 60) end at 597992.
Task 1(120, 75, 60) start at 600001.
Conclusion

- EV3OSEKs faults have been analysed.
- Multitasking is enabled in EV3OSEK.
- The proposed implementation works.
## Current State of EV3OSEK

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<th>Comment</th>
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<td>Lego EV3 sound sensor</td>
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